ADDRESS BY

Dr. James C. Fletcher

Administrator

National Aeronautics and Space Administration

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SPACE AND THE ENVIRONMENT

It is a real pleasure to return to my old home town and address the Western Association on space, and the things we in NASA are doing which are related to environmental affairs.

A major part of our space program activities in this decade are focused on Earth observations and applications. These activities are designed to help efforts to improve and conserve the environment, our natural resources, and the ecology. I believe they will open many eyes to the utility of space for our everyday lives.

But before going into that, I would like to take just a few minutes to comment on Skylab.

About two months ago, a new dimension was added to this nation's space program.

The lessons learned through more than ten years of space flight activity were brought to a focus that combined man with the most sophisticated set of instruments ever devised for looking at our planet.

In May, Skylab, a three-man space station equipped with a most advanced array of instruments for sensing the factors that most influence our environment was launched.

Skylab is truly an outgrowth of the space program. Everything we have ever done in space contributes directly to the success of this flight. The astronauts from Gemini and Apollo; the spacecraft from Apollo; the instruments from every space probe or satellite we've ever flown.

All of you, I am sure, have read or heard of the difficulties which initially beset our first orbiting space station. You know how these were overcome by skill, daring and improvisation in the best traditions of America. Despite these difficulties, astronauts "Pete" Conrad, Joe Kerwin and Paul Weitz managed to repair their space Workshop and complete all but a small number of their planned experiments and Earth observations. And after a record 28 days in orbit, and 11 1/2 million miles of space travel, they have now come back in amazingly good physical shape.

Skylab demonstrated at least two significant things quite apart from its assigned mission:

First, I think the whole performance is a reaffirmation of the American ability to pluck triumph out of potential disaster. The intrepid skill and daring of our astronauts, the tireless determination and ingenuity of industry-NASA teams on the ground, are nothing less than inspirational. The whole country can be proud of their accomplishment.

It also should comfort those people who feared America was losing its ability to meet challenges. It should restore confidence that American resourcefulness in scientific and industrial technology is a trait, not a myth. Even the British press, not given to overstatement, remarked on the "superb capability" of Americans in this respect.

The only question that arises in my mind is, how often must Americans demonstrate these qualities before the doubters regain confidence in themselves and their country again?

Second, Skylab's difficulties demonstrated the great value of the presence of man when emergency repairs are needed in space. Were it not for the astronauts' "fixit" ability, NASA and the nation would have had a public embarrassment on our hands, or rather in the sky, for all the world to see. Instead, we had a triumph.

But more than that, extrapolating from the Skylab experience, we believe that human capabilities will have thousands of uses in space. What the astronauts did in operating a solar telescope, conducting scientific, medical and industrial experiments, performing Earth observations -- in addition to their virtuosity in repair work -- all point to the broad scope of human capabilities in space. Even the optimists among us didn't expect so much so soon. And to think scoffers not long ago were saying that if man could exist at all in space, he'd just go along for the ride!

Skylab taught us a great many things. One of these was that the astronauts go through a rapid learning curve. After only a few weeks in zero-gravity conditions, they became so proficient at their assigned tasks that we had to do some quick planning to keep them fully occupied. We also discovered that some tasks originally designed for two astronauts could be done handily by only one.

The secret to efficient human performance in weightless condition, we learned, is adequate, well-designed body restraints. You can't even turn a screw-driver without being anchored to the deck. This is a lesson Skylab in particular drove home to us, and it is one that won't be lost on us for the future.

The first of three missions involving Skylab is now history and the next is to begin in just over two weeks. The second mission will have a new, three-man crew, manning the station for almost two months and operating the sensors, collecting reams of data about the Sun and of perhaps more immediate interest, about the Earth. A third and final mission similar to the second will be flown in the fall. Skylab carries what is called an Earth Resources Experiment Package (EREP). This is a group of cameras and other sensing instruments that are designed to collect data that will make better management of our natural resources possible. This package of instruments complements and extends the data gathering capability of the Earth Resources Technology Satellite (ERTS) which was launched just about a year ago. Most importantly it includes a human observer who for extended periods is able to operate the instruments and, as illustrated over the last few weeks, keep them operating.

The sensors in the EREP package are really quite remarkable. They can detect such things as temperature differences in water or on land making possible the detection of certain forms of pollution as well as potential sources of thermal energy. Other sensors can measure sea state and tell us how rough the ocean is and help us relate this to weather conditions. Crops can be identified and certain indications of their well being can be perceived. Data from both EREP and ERTS will move us much closer to having the skills and knowledge needed to design space systems that will provide continuing benefit to all mankind.

We have not yet fully examined the data from the first Skylab mission but what we have seen lives up to our most optimistic expectations. Data from both EREP and ERTS can be processed by computers and analyzed to make comparisons between such things as soil type and condition, moisture content, crop types and even the use to which we put our land. Very much like ERTS data from EREP will be used in experiments concerned with many subjects of interest to man including crop and forestry cover, the health of vegetation, types and conditions, surface or near-surface mineral deposits, water storage in snow packs and sea surface temperatures.

In any program to improve the environment or to save endangered ecologies, observation is essential. It is perhaps trite to even mention it, and I do so only because space offers us a new vantage point from which to observe, to learn about the Earth's surface, in a way that provides an entirely new and useful perspective. We are using the laws of physics, of orbital dynamics, to help us. We have learned how to place spacecraft in different orbits for different purposes.

For example, a satellite can be made to orbit the Earth from pole to pole while the Earth spins 570 miles beneath it. Such a satellite repeatedly passes over every spot on the planet at exactly the same time of its previous pass 18 days earlier.

Another orbit we use is called geosynchronous: here we place a satellite out at a distance of more than 22,000 miles, and as the Earth spins, the satellite keeps up at the same speed and therefore hovers over the same point on the Earth's surface. About 1/3 of the world's surface can be covered from that position, so only three such systems can serve the entire world.

Still another means to observe the Earth and its phenomena is a manned space station, such as Skylab, which orbits the globe every 93 minutes at an altitude of 270 miles.

Nearly all the Earth's land surfaces can be viewed and monitored from such a space vehicle, using instruments, human eyes and human judgment. Particular phenomena and events of special interest can be singled out for more extensive attention by astronauts manipulating sensors and cameras, a capability not present in unmanned satellites. But, in addition, the astronauts bring back the film which contains much greater detail than pictures beamed back to Earth from automated spacecraft.

So, with space technology, we not only add to the conventional methods of observation, we also provide a new and wider perspective. We can photograph thousands of square miles in one picture frame from the space platform with a clarity and wealth of detail that seems unbelievable at altitudes of hundreds of miles. Equally important is the fact that the lighting is the same over the whole region included in the view, a vital factor in photo-interpretation. Aerial photography of the same area, for example, would require 100 pictures approximately for each space satellite photograph. And when the aerial pictures are pieced together in a mosaic of the region, the lighting varies so much that features often are lost altogether.

However, the aircraft and spacecraft can work admirably together when space photos reveal features requiring closer examination, particularly when remote regions are involved.

To exploit these new vantage points, we have been building and experimenting with a wide variety of new environmental tools -- tools that can serve to enhance the quality of life here at home. I want to stress that the systems we are developing are just that -- tools -- and must not be thought of as technological solutions in themselves to environmental problems. The basic purpose of these space tools is to collect and communicate <u>data</u> -- measurements, observations, pictures -- from which <u>information</u> -- conditions, predictions, changes -- can be extracted.

Short- and long-term solutions to basic problems come from enlightened decisions -- and such decisions are the result of very complex social, economic, and political processes. However, all decisions are ultimately based on some kind of information base, and the better the base, the wiser the decisions that can be made, and the more far-sighted are the policies that can be developed.

So the technologies of space exploration and utilization are not panaceas in any way. But they are potential major contributors to the information flow necessary for wise decisions.

I would note, too, that technology can be a uniquely powerful force -- I call it "impactful" -- in the creation of public policy. It can provide a real forcing function in arousing public awareness of issues, of alternatives to the way we do things, and of potentials for the future.

We like to believe, for instance, that man's first views of his world from the barren surface of the Moon (Figure 1) -- the astronauts' perspective of our tiny, blue-white, beautiful but fragile planet -- has done much to spread among all men the understanding long held by only a few that the world is indeed finite and unique, the one home of humanity. I believe that this view, reinforced as it is by a new sophistication in understanding interrelated events and conditions, is a very important social force that is creating a new context for informed action, ranging from the individual to the global.

The same has held true for the technologies of transportation and communications: the ability to shrink time and distance, to provide any one with access to any place -- in person, by voice, by picture -- has already revolutionized society, and eliminated many of the barriers between people that hampered joint action for the benefit of all.

The environment of man as he usually perceives it is, of course, local. We also know -- and are bringing it home harder each day -- that his local environment relates both directly and indirectly to regional, national, and global phenomena, forces, and conditions. Our information systems therefore must be tailored to deal effectively with each of these levels of demand. Space systems, inherently global, lend themselves uniquely to overviews of the largest problems and, because of their capabilities, can contribute directly as well to every intermediate level down to the smallest.

I will try to illustrate these points as I go along. I would like to draw for you two different views of the future -- not the distant future, but the one we can all expect to see for ourselves -- and then to argue with one of these projections in favor of the other.

In discussing these forecasts of alternative futures, first the bad news:

Many of you here may be familiar with the recent work by Forrester, Meadows and others in modeling global population growth and economic development, the dynamics of a global society. From this work at MIT came the famous "The Limits to Growth" report of the Club of Rome.

The main thesis of the Club of Rome's report is that population, pollution, and consumption are increasing exponentially -- Malthus, in the 1800's, used the term "geometrically" -- but that the planet-wide capacity to deal with these rates of growth is essentially fixed. As they vary the assumptions, so they can vary the predicted future. But in each case they studied, they came up with essentially the same conclusion: if world population and consumption of resources are not made to stop growing -- the "zero growth" approach -- there will be a total, catastrophic collapse of world civilization by the year 2100 or thereabouts.

Now, whether we agree with the Club of Rome's predictions or not, the report has already made a real contribution. It generates useful debate. It exposes real problems in manageable terms. It shows the values of modeling the real world -- both socially and physically. It leads us to recognize that many things are subtly interrelated and that these are often not intuitively obvious.

There is, in short, real merit in looking at the world as a system and in learning how to measure the future impact of current activities -- it is a truism that we often set out to accomplish a given end, and then wind up having created a larger problem than the one we started out to solve.

Now I emphatically do not subscribe to the doomsday view of world civilization. That view overlooks man's capacity for self-preservation. Man can learn and can act, and thereby can control in large part his own destiny. Science and technology are among the tools with which he can -- and will -- shape his future.

If mankind understands early enough the implications of action or inaction, if accurate information is readily available at every level of interest, then I see a continuing process of adaptation based, not on the destruction of the environment, but on its wise management.

Let me ask you to suspend any natural suspicion or disbelief for a moment and imagine a world 15 or 20 years from now that has taken advantage of some of the scientific knowledge and technical capabilities space exploration has created already.

Take the climate (Figure 2): think of a global weather network made up largely of observation satellite systems that constantly pour data into a computerized prediction system. This will let anyone have a "now-cast" of the weather at any place in the world, as well as an up-to-date and accurate forecast valid for up to two weeks -- also for any place in the world. The economic values of knowing -- not guessing -- what the weather will be are enormous: they apply to farming, construction, to transportation, to recreation.

With the kind of understanding that such information and prediction capability provides, it isn't far-fetched to postulate operational, purposeful weather modification and climate control (Figure 3) -- on a local, regional, and global basis.

The implications for human affairs are staggering -- to eliminate the dangers and destruction of hurricanes, to relieve droughts, to ameliorate living conditions, to increase productivity, to balance imperiled ecologies -- the list goes on and on.

Take water (Figure 4): our consumption rate is increasing as personal, agricultural, and industrial demands grow. Even if we manage the rainfall, or desalinate sea water, we still will have to husband this most fundamental part of the life chain. By measuring the change in the snow pack, by knowing the weather, by having stream gauges to monitor the flow, quality and temperature and report back via satellite to central facilities, by watching erosion effects, pollution sources and usage patterns, we can develop regional water management systems that combine the esthetic and the practical.

The same will be true for land use (Figure 5): We will have on call not only truly current satellite-generated map analyses of how land is being used, but -- because of the repetitive nature of space orbital coverage -- we will also be able to have historic information on land use changes over the years and computer-based projections of where we are headed. The planners, the builders, managers, lawmakers, farmers will all be able to make their decisions based on timely information displayed in the form best suited to their particular interests.

Take agriculture (Figure 6): space-based systems can detect diseases and insect infestations before the forester or farmer can. Crop quality and size can be predicted. Planting and harvesting can be coordinated on a national and international scale. Productivity is balanced with conservation; wasteful and marginal activities can be reduced; current and accurate analyses of carrying capacities, runoff and erosion, crop classifications, soil type and fertility are readily available.

Take the encompassing subject of environmental quality (Figure 7): again, space systems observe, measure, and communicate, acting in conjunction with aerial and ground-based and water-borne instruments. Information is instantly available -- to everyone concerned.

Are earthquake stresses building up? Minute motions and stresses are measured by automated monitors and the data relayed to satellites -- if a crisis is imminent, regional warnings are broadcast via space systems; or if time permits, measures may be taken to relieve or redirect the growing stresses or limit the damage.

Oceanic farming has replaced hit-or-miss fishing; we monitor sea-state, temperature, nutrients, and ocean quality as routinely as we now do the rainfall. Atmospheric quality is monitored by space-borne instruments.

No part of the changing, moving face of the globe we inhabit is free of human influence or removed from human interest. We therefore can afford to leave no part unmonitored. From forest fires to hurricanes, from slow erosion of granite hills to the short-lived volcanic eruptions or avalanches, from atmospheric particulates to crop diseases to oil spills -- we need to know the condition of our environment, minute by minute. And from that kind of knowledge -- perhaps only from that kind of knowledge -- can and will flow the interrelated set of local, national, and international measures that will make our planet what we want it to be.

Everything I have suggested here is already possible -- the technologies exist or are under development. The key is to know how they will be deployed and how they will be used. I personally believe that the greatest lag today is in the development of mature social and political institutions to collect, manage, and act on the whole new level of environmental information we are able to generate.

I also believe that, as some of the current activities I will be discussing shortly come to fruition, their major impact will be to force the development of a new level of maturity on society. The kinds of models I have described have to be widely used and respected in order to contribute their full values. One great contribution they can make is to test actions by simulation: you can pose the question, "what will happen if I build this dam, drill that well, plant this crop, re-forest that tract?"

A good environmental model will warn of potential problems -- erosion, changes in fertility, siltation, water table depletion, ecological reversal. The same model will guide action toward real benefits, indicating the proper rates of exploitation commensurate with a natural or managed cycle of resource renewal.

But will people educate themselves to the use of such predictive tools? Can short-term self-interest give way as needed to recognize the need for long-term balance?

I believe so; and some of our work is beginning to show the way.

I have touched on the basic observational and communications tools that the space program is creating for man's use in the wise management of the planet. These tools, especially some of the newer ones, are opening up whole new fields of study and application.

It is a little like the invention of the x-ray machine. Suddenly, a new diagnostic tool was available for medicine, a profession that had been slowly learning for millennia. All at once, the doctors could see what before they could only guess at -- the condition of living tissue, undisturbed by the intrusion of scalpel or probe. This was remote sensing on a small scale. Today, we use satellites and their sensors in the same way -- but on the scale of the whole planet.

From remote space, we measure temperatures, colors, shapes, distances, movement, change. From these measurements we can deduce environmental condition. We are learning that every object -- or class of objects -- has its special "signature" which can be recognized from instrument readings. We are learning to interpret -- and as we do so, we learn what other related parameters and phenomena we need to observe to get a total picture. We are really at the threshold of the tomorrow I have just attempted to sketch.

Let me show you some of the things we are doing today.

Here (Figure 8) is a dramatic shot of Earth and its weather patterns. It was taken from Apollo 16 last winter. You can easily see the very complex cloud formations, the storms, and the atmospheric circulation systems.

Several years ago we took a series of time-lapse pictures like this from a research satellite in synchronous orbit. We then had a movie of this hemisphere's weather -- and in color! Today, weather satellite systems are operational under the management of the Department of Commerce -- I am sure you are all familiar with the TV weather reports that show the latest satellite picture of the regional cloud pattern.

These same satellites can map the temperature all the way from their altitude to the surface, an important input to forecasting. Next January, the Commerce Department will also be operating the first of its geosynchronous satellites. We expect they will strengthen enormously both their forecasting capabilities and the fundamental understanding of the atmosphere.

Moving now to the other extreme of distance (Figure 9), here is one of the instruments we are studying. In the tank is Virgil, a live Chesapeake Bay oyster. The oyster is a potentially excellent water quality monitor -- it stays in one place and, to eat, filters a great deal of water through its system.

The oyster's heart beat, being recorded here on an EKG instrument, varies with the oxygen content of the surrounding ocean. The oyster, as you know, is a valuable economic resource, and disappears early from polluted waters. It may be possible to use living oysters as direct monitors of their own environment, perhaps communicating with an instrumented buoy which in turn can relay the measurements via satellite.

Another (Figure 10) similar approach is to instrument a blue crab. In this case, the blue crab is an agile, aggressive animal that seeks the conditions that suit him best. His blood stream responds to the salinity of the water he inhabits and his heart rate indicates his health. The miniature backpack is self-contained and transmits through the water to a separate receiver. This technique may help in understanding the effects of pollution on this valuable food species.

Another aspect of water monitoring is understanding its chlorophyl content (Figure 11). Chlorophyl means plant life -- a major supplier of oxygen to our atmosphere, as well as the base of the oceanic food chain. Here we are using a space picture taken by the Earth Resources Technology Satellite (ERTS-1) off the coast of Morocco in combination with an oceanographic ship, whose track is a black line.

The ship took actual sea water samples and measurements at the points shown, so we knew how much chlorophyl was there. Analysis of the space image produced the remarkably similar curve shown below, thus pointing the way toward the capability to map and monitor the global oceanic productivity from space -- easily, cheaply, and completely.

In the same way, we can identify those cold water upwellings in the oceans which bring nutrients to the surface, and which are so important to our fisheries.

Another kind of water mapping is shown here (Figure 12). This is Clear Lake, so-called, in California. The contours here indicate different levels of chlorophyl concentration. We collected data for this analysis from an instrumented aircraft as part of developing techniques for environmental monitoring.

In this case, chlorophyl concentrations are the symptoms of pollution, the kind that leads to the well-known phenomenon of euthrophication or deoxygenation. Parenthetically, I can add that space imagery is being directly used now in anti-pollution programs. Here (Figure 13) is an enlargement of a black-and-white ERTS picture being used as supporting evidence in an anti-pollution lawsuit. This is southern Lake Champlain -- the State of New York is on the left, Vermont on the right. The dark smear in the center of the lake is the plume of polluted waste water from a New York paper mill.

Also using aircraft-borne instruments, we have been able to find oil slicks (Figure 14) resulting from spills or leaks. We feel that these techniques extrapolated to space will be able to provide a world-wide warning system able to identify even those very thin slicks that escape even closeby human eyes unless the sun angle is just right. When you realize that there are about 10,000 oil spills each year in United States waters alone, there is no question as to the importance of monitoring this problem closely.

From space, ocean pollution looks like this (Figure 15). This is the New York Bight with Long Island at the top. The "g"-shaped feature is the mark left by the dumping of waste acids into the ocean -- a normal disposal technique today. It is interesting that this picture was taken 14 hours after the dumping. Clearly, the oceans are not the limitless sink they were once thought to be. To the left of the acid dump you can see the mark of a sewage outfall.

The image was enhanced especially to highlight water pollution; we can manipulate the data from these space systems to bring out other features, depending upon the area of interest. For example, one of our investigators is using ERTS imagery to spot and characterize turbidity in the Mississippi Sound. There is an apparent affinity on the part of menhaden for turbid waters. If successful, this technique will improve the catch of menhaden, a commercially valuable fish used mainly for fertilizer.

A major use of space data is expected to be for watershed management (Figure 16). This is the Cape Fear River watershed in North Carolina, outlined on an ERTS image.

Let me say a word about the color in these ERTS satellite pictures: the sensors on board suppress the color green to make it easier to handle the data. When we reconstruct one of these images on the ground from the satellite telemetry, the shades of green are reproduced as shades of red. The African nation of Mali plans to develop its first definitive water resource inventory using ERTS data.

Another example (Figure 17) of ERTS utilization for hydrology is the measurement of snow cover. Here are the Grand Tetons last September, with the peaks covered with snow. The satellite can take a picture of this area every 18 days; as the season progresses, the increase in snow cover can be measured and plans for handling the spring runoff made.

In addition, we can monitor stream flow with instruments that report back via satellite. Last October, for example, one such sensor in Arizona allowed a reservoir manager to preserve the impounded water rather than release it unnecessarily and destroy roads and fields. It is this kind of information that water managers will use in protecting against floods, in allocating water for agriculture, in planning impoundments and hydroelectric power facilities.

I will move on now from water to land (Figure 18). This is, I feel, a magnificent example of the kind of information we get from space systems. The area included in this ERTS picture is more than 12,000 square miles -- the frame covers 100 nautical miles on a side.

We are looking at Lake Mead to the left with the whole of the Grand Canyon extending to the right. A single picture like this is an instant geologic map of the area, and one that can be made again and again to monitor seasonal changes or the behavior of -- in this case -- the Colorado River. It would require thousands of conventional aircraft pictures and years of work piecing them together to map this same area. ERTS takes its pictures in seconds, and we can reproduce them in usable form in a matter of days. Remember, these are not true colors, of course. The light red or orange patches and strips are really the greens of vegetation -- grass, trees, and scrub on the plateaus, agricultural crops along the Virgin and Meadow Valleys running north from the Lake.

This next picture (Figure 19) has two points to make: it is a picture of Nicaragua and Honduras; the Pacific Ocean is to the south, Lake Nicaragua to the east. It is easy to see the drainage patterns here, and the sediments streaming into the Gulf of Fonesca on the left. The geologist, however, sees something else as well: he sees the chain of volcanoes trending along the coast toward the southeast. He notes that Managua, the capital, lies directly on this fault system. (The city is under the small puffy clouds at the extreme right of the picture.)

Nicaragua was planning, just before the recent disastrous earthquake, to install remote unattended detectors along the fault -- detectors that would warn of impending volcanic activity by relaying their data via the ERTS satellite. If these had been in place in time, we feel that their warnings could have been extremely helpful.

Similar instruments are in place on the slopes of a volcano in Guatemala; just recently, they reported a significant increase in seismic activity -- from 5 to 80 events per day -- and two days later, the volcano erupted.

This next picture (Figure 20) is of a familiar area -- Egypt, the Nile, and the Mediterranean. It was taken in 1966 from Gemini 11 with a hand-held camera. In this case, the colors are accurate. I have included it here since it represents one of the first examples of successful mineral prospecting from space. Analysis of this picture showed that chromite ore deposits extended much further than suspected, even in this region that has been so intensively inhabited for so long.

Here is an Apollo 9 photograph (Figure 21), also in real color, of Arizona. Geologists examining this picture found very large connected features not visible from aircraft. They also saw for the first time a structure recognized as being associated often with copper deposits. Their analyses were turned over to the owners of this particular area -- the Apache Indians.

This slide (Figure 22) is almost self-explanatory. It is an ERTS picture, in black-and-white, of the Alaskan North Slope region. Note the very careful and cautious wording by the Department of Interior, who did the analysis. One of their reports says, "... the lineation may reflect subsurface structures in rocks potentially favorable for petroleum."

If further seismic studies on the ground prove out, I expect there will be test wells drilled before too long. If the wells prove out, we may have found petroleum reserves here in quantities sufficient to have a real impact on the energy crisis.

Here is the Imperial Valley in California (Figure 23) as seen by ERTS in September last year. You can see the individual fields -- red being the ones still having crops at various stages of growth, the blues, blacks, and whites being those that have been harvested or plowed.

You can see intensive cultivation along the Colorado River and in the irrigated lowlands. It is possible to make very rapid acreage and yield estimates from data of this quality, especially since we repeat the coverage every 18 days. You can also see how these pictures are really current land use maps in themselves, and how they can provide a whole new data base for regional planning, water management, and productivity measurement.

Another apsect of remote sensing for agriculture is the early detection of crop stress and identification of remedial action. Two years ago, the southern corn blight threatened a large percentage of the midwestern corn harvest. As you can see (Figure 24), blighted corn has the distinct infrared signature which allows us to detect and measure the extent of the infestation. We learned to recognize several different levels of disease and we can now monitor the crop impact (Figure 25).

Here we see fields in Indiana; the letters represent different crops such as alfalfa or clover and the numbered fields are planted corn. Each numbered field has been accurately assessed in terms, not only of the severity of the infestation, but also as to the maturity level of the crop. We have many other investigations under way in the area of crop protection -- one of the more interesting ones is the use of ERTS pictures and weather data to predict the environmental conditions that lead to locust plagues in Africa. If this is successful, it points the way toward controls over this pest that has repeatedly struck African agriculture since Biblical times.

This next illustration (Figure 26) is a map -- a detailed land use map -- of the area around Houston, Texas. In this case, we used aircraft photography as the data base and, from that, were able to break down the current employment of land into the 20 categories shown here. You can see the value of this kind of thematic mapping, even if it is done, as this was, on an experimental basis to identify the level of meaningful detail readily obtained from aerial photography. A complete series of 21 of these maps is now being offered for sale by the Department of the Interior.

An even more recent example (Figure 27) is this land use map of the state of Rhode Island. This was made from a single space picture -- and it took only 40 manhours to do it. It replaced the state's other most up-to-date land use map -- one just two years old.

If we tried to do this kind of inventory with standard techniques using standard aircraft photography, we would have to spend some 16,000 manhours to reach the same point. The view from space, properly used, gives us an improvement factor of 400 in time and cost. But even more important, the information can be kept absolutely current with very little effort. In cases where there is no prior base of information, this technique becomes extremely valuable. Some countries are even using these techniques to develop their population statistics -- a kind of space-based census that permits rapid identification of remote villages and hamlets.

This picture (Figure 28) is also from ERTS but enhanced to highlight the river structure of the Amazon. The Brazilians have been very enthusiastic about this satellite picture: they have found their existing maps and charts to be quite inadequate. For example, whole new islands have been found up to 200 square kilometers in size; river courses and positions have now been corrected -- sometimes the old maps even showed the river flowing 90 degrees in the wrong direction.

In summary, Brazil has found that ERTS is giving them better data than a $20 million airborne mapping project -- and at 100 times less cost. Brazil plans to install its own ground station to receive space data directly, just as has Canada. I expect a number of other nations will soon follow suit.

As fish and game commissioners, you will have a special interest in some NASA activities concerning birds. We are using radars at our tracking stations to study bird migrations (Figure 29). We hope to be able to distinguish individual species by the unique radar signatures of their wing beats and flight characteristics.

We are also trying to learn something about whales (Figure 30). Here is an instrument package attached to a California gray whale. The instruments record information on the whale's location, oceanic environment, and its physiology. We get the information back by letting a sequential series of miniature buoys pop to the surface and transmit to an aircraft or satellite. When the last of these little buoys is gone, the harness itself will have corroded and dropped off the whale. The attachments are made with very precisely calibrated bolts that corrode at a predetermined rate. A similar approach is being tried out for tracking marine turtles (Figure 31).

Also, using miniature radio packs, we have tracked land animals from satellites. Here (Figure 32) are the results of one such experiment at an elk refuge. We were able to locate and map the movements of the instrumented animal by satellite. You can see the elk stayed within a ten-mile or so area during the 28 days of the test. Currently, we are doing the same test with bears; their instruments will monitor the animals both when they are on the move and when hibernating.

Perhaps our most attractive wildlife asset is the Kennedy Space Center, our Florida space port. Over the years, we have turned most of the Center's 140,000 acres into the Merritt Island Wildlife Refuge, while still conducting our major business, the launching of manned and automated space missions. The refuge has identified more than 250 species of birds, including (Figure 33) the rare and endangered dusky seaside sparrow.

There are over 2,000 alligators (Figure 34) in the refuge, as well as bald eagles (Figure 35) -- four active nests this year -- marine turtles that nest on the beach, some 200 bobcats and 300 otters, shore birds and wading birds (Figure 36), and even feral hogs.

I cordially invite all of you to visit this refuge to see for yourselves how we have been able to integrate a major high technology activity with the local environment for the benefit of both (Figure 37). This picture of the Apollo 13 launch perhaps symbolizes best what I have tried to sketch for you: technology and ecology can be not only compatible, but each serves the other with gains on every side -- a symbiosis of civilization and the environment.

I have tried, in this summary overview, to touch upon some of the values space and its attendant technologies can contribute to the planet we occupy. Let me assure you that this talk is far from exhaustive. For every example I have cited, I am sure there are 20 more. Just recently we had a symposium for investigators and researchers using data from the ERTS program -- over 180 technical papers were presented, and many others could not be fitted into the schedule.

We are going forward in this area. NASA's near-term flight program includes, among others, another Earth resources satellite, a radar satellite to map ocean levels and motions, a very precise space reference to help pinpoint the relative motions of the continents, and prototypes of two new high-performance weather systems.

By the end of this decade, in order to make real some of the concepts described earlier, we will have the space shuttle to allow us the same kind of easy and inexpensive and rapid access to space that the airplane has provided around the globe.

What then are the major challenges that we face?

We still have much to do in learning how to extract the greatest benefits from our technology.

We have to learn how to extract, display, and use the information our tools provide, rapidly, easily and cheaply.

We must develop and expand natural and predictive meodels of the environment so as to provide the kind of real assessments so vital in real-world decision-making.

These are NASA's jobs -- research, development, pioneering, showing what can be done and how to do it best. We are working hard on them.

An even bigger job, however, is the development of competent local, regional, national, and global institutions that will build and operate such systems, that can assimilate and act on a new class of information, that can manage and control with wisdom the resources and environment of mankind. In this task, the NASA accomplishments and the NASA program can serve as catalysts -- but the responsibility for action really lies with everyone. The individual, his local and state governments, his Federal departments -- all have major roles to play in assuring the proper employment of technology by man for sake of mankind.

That, I believe, is the real challenge the space age has posed for the world.

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